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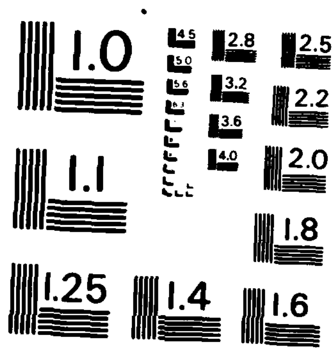

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Phase and Amplitude Measurements of Individual Dipoles of 450-800 MHz, 9-Element Array

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30 September 1985

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The results of phase and amplitude measurements of individual dipoles in a 9-element (3 × 3 configuration) array are presented. The 3 × 3 array, designed for 450 to 800 MHz operation, consists of 9 open-sleeve dipoles. Using sweep frequency measurement techniques, the phase and amplitude characteristics of each individual dipole are compared to the center element for both vertical and horizontal polarizations.

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I. INTRODUCTION

The phase and amplitude frequency response of dipoles in an array are often needed for those interested in the transfer function of a dipole in an array configuration. A knowledge of transfer functions is useful for phased arrays, active aperture and adaptive antennas. A 9-element (3 × 3) open-sleeve dipole array was chosen because of its wide impedance bandwidth characteristics and its availability in the laboratory. The array operates from 450 to 800 MHz, and its RF characteristics has been described in Ref. 1. The phase and amplitude characteristics of each of the dipoles with respect to the center element are described in this report.

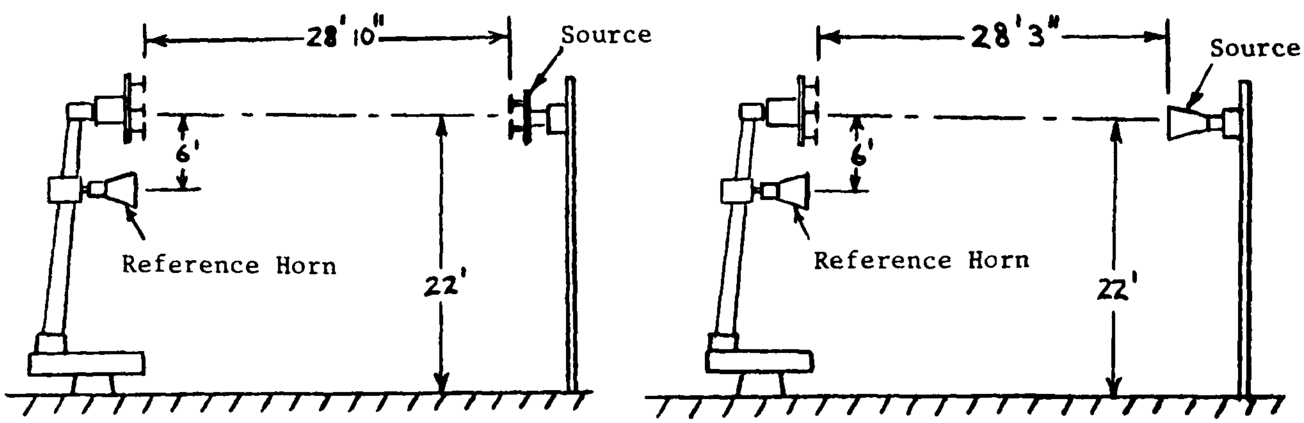
Each element is a crossed dipole, 10" long, mounted 5" above a 52 in. square flat reflector, which was constructed with 0.5 in. mesh hardware cloth. The dipole-to-dipole spacing is 16 in. For these measurements, only one set of dipoles (identified as the "A" set) were used with the orthogonal B dipoles terminated in 50Ω. The array feed network, consisting of a 9-way power divider circuit, was not used in these measurements since the interest was in obtaining the transfer function of each individual dipole. RF characteristics of the 3 × 3 array, including patterns, gain, axial ratio and VSWR are described in Ref. 1.

II. DESCRIPTION OF TEST SET UP

A. Physical Arrangement

The dimensions of the test range configuration are shown in Fig. 1. A 2×2 array and a Nurad horn were used separately as source antennas. With a 22 ft source height and ~ 28.5 ft range distance, the ground specular reflection angles from the source to the dipoles under test and the Nurad reference horn are ~ 57° and ~ 53°, respectively.

Initially the reference horn was supported on a separate tower and it was found that with only a "slight" amount of wind, it was sufficient to cause erroneous results. Subsequently, both the reference horn and the 3×3 array were mounted on the same fiberglass support tower. In addition, it was necessary to stabilize the mount with screw jacks before repeatable results could be obtained.



(a) 2×2 Array Source

(b) Nurad Horn Source

Fig. 1 - Dimensions of Antenna Range

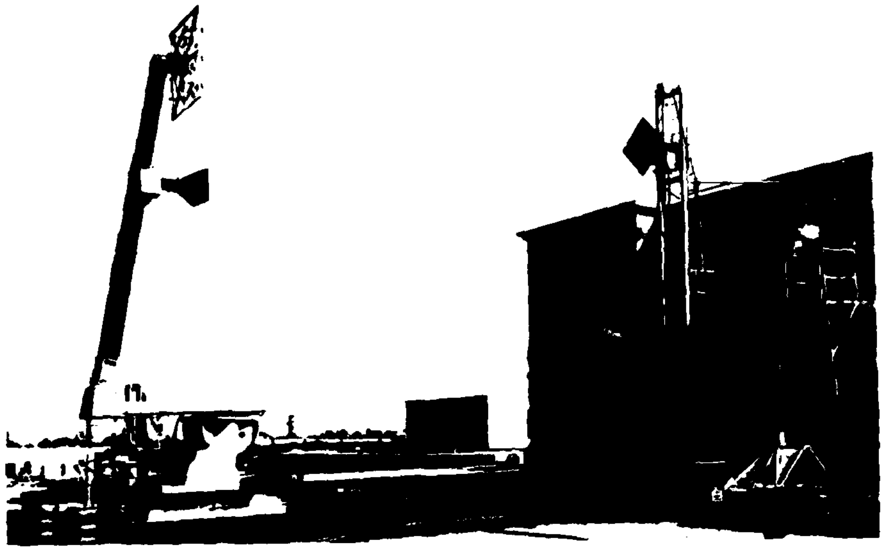
Two 30 ft long phase-matched cables (Microflex, No. 165) were used to connect to the reference horn and dipoles under test. The cables were secured to the fiberglass support mast. The location of the cables in the rear of the array was found to affect the results, so care was taken to place the cables in approximately the same location for each measurement. To assure symmetry in the cable routing the dipole cable was threaded through the center of the test-tower "head".

Figure 2 shows photographs of the antenna range displaying the 3×3 array on the antenna-test positioner. The reference horn (Nurad Model 7RH) is attached to the fiberglass tower, 6 ft below the array. The source antenna shown in Fig. 2 is a 2×2 array operating in a diagonal mode to yield low sidelobes and reduce multipath signals to < -25 dB. During the course of these measurements a Nurad horn, whose beamwidth is much wider than the 2×2 array, was also used as a source antenna. The data collected from this wide-beam pattern horn source antenna is compared with the narrow-beam pattern 2×2 array source.

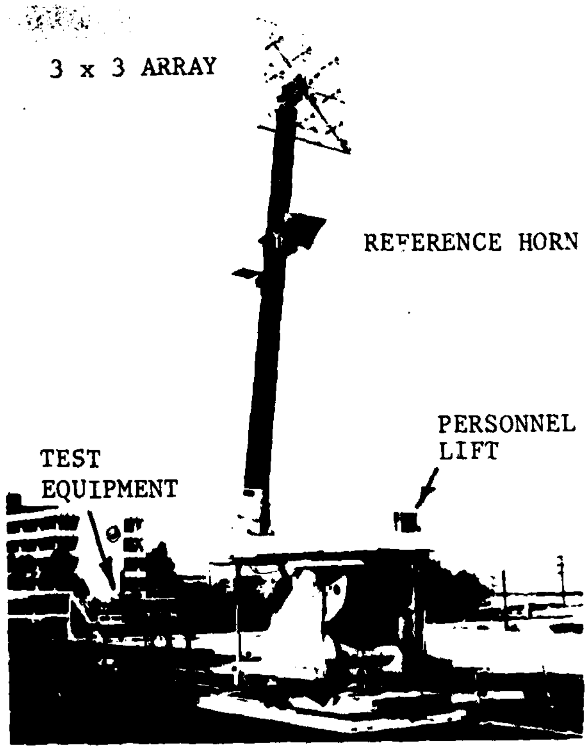
Since the array height is ~ 23 ft above the deck, a personnel lift (see Fig. 2b) was used to raise and lower the person connecting/disconnecting the cables to/from the dipoles. The lift had to be lowered during each of the measurements, as the height of the lift affects the measurements. Furthermore, even with the lift completely lowered, the physical location had to be fixed during the duration of the measurements.

B. RF Test Equipment Arrangement and Characteristics

A HP 8754A network analyzer was used for the phase and amplitude measurements. It is a self-contained unit complete with sweep oscillator, couplers, detectors, signal processing and outputs to an external X-Y recorder.



(a) Overall View of Antenna Range.



(b) Closeup view of 3 × 3 array, reference horn, personnel lift and test equipment.

Fig. 2 - Photographs of Antenna Range and Equipment.

The block diagram of the measurement setup is shown in Fig. 3. The network analyzer was placed at the base of the test-positioner mount.

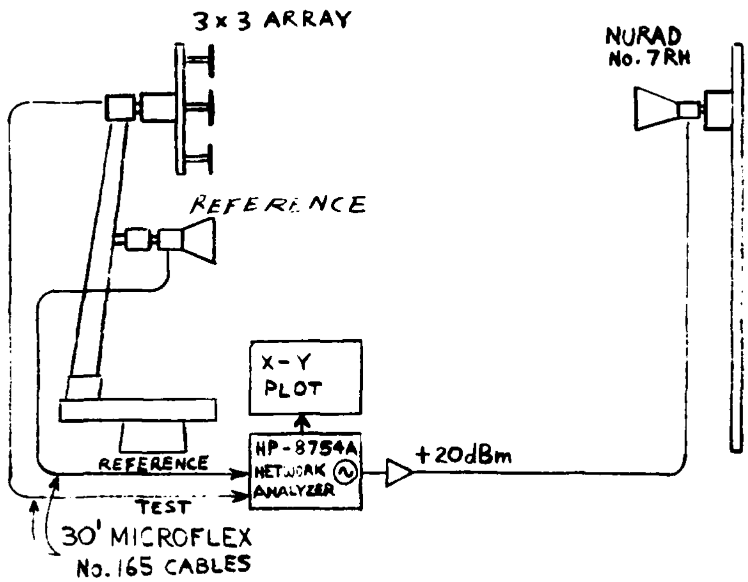


Fig. 3 - Block diagram of phase and amplitude measurements.

Two different source antennas were used -- a wide-beam, ridged horn and a low sidelobe 4-element array. The 4-element crossed-dipole array (dipole spacing = 13.75") was used as a diagonal array to provide low sidelobes for maximum multipath rejection as can be seen from the patterns of Fig. 4. The pattern levels wrt beam peak at θ = 56.8° are tabulated as follows:

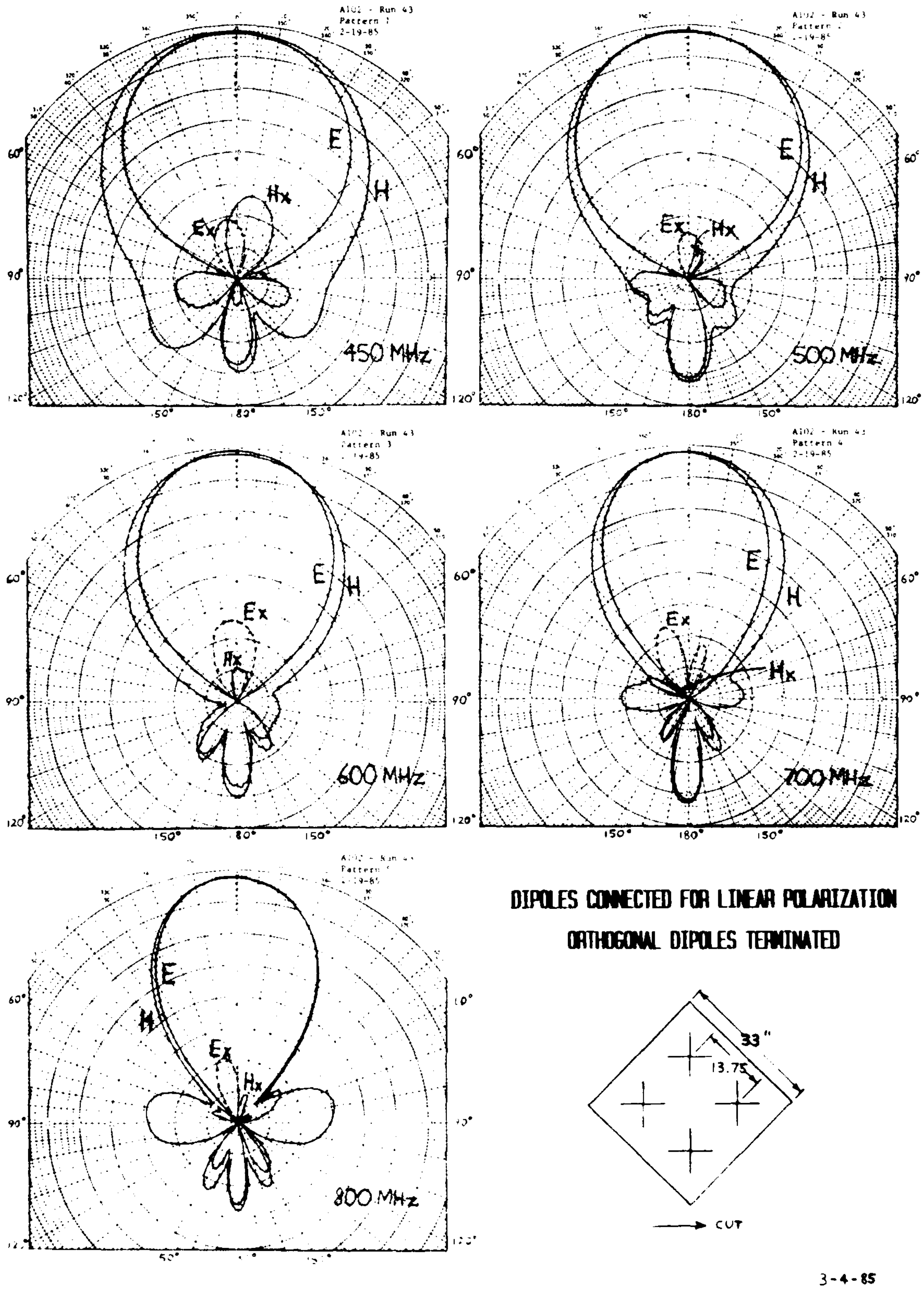


Fig. 4 - Radiation patterns of 4-element array source antenna.

Frequency MHz	Pattern Level wrt Beam Peak (56.8°) Horiz. Pol. dB	Vert. Pol. dB
450	-14	-22
500	-18	-23
600	-22	-34
700	-29	-34
800	-31	-31

It is estimated that additional multipath rejection of 11 dB can be attributed to the following parameters:

- Additional space-path loss (multipath ray) = 5 dB wrt direct path
- Ground reflection coefficient ≈ -3 dB
- 3 × 3 element-pattern level (56.8°) = $\leq$ -3 dB

Therefore, $\geq$ 25 dB multipath rejections are expected over the test frequency band. Although the elements were in a crossed-dipole arrangement, only one set of linear dipoles were connected and the orthogonal set terminated in 50Ω for the measurements. In Fig. 4, the letters E and H represent the E and H plane copolarized patterns, while EX and HX signify the cross-polarized signals in the E and H planes, respectively. In addition to the ground-multipath signals, which cause errors, the cross-polarized components ($\leq$ -25 dB) of the source antenna is also an error source.

In contrast, the Nurad horn, with an aperture of 18 × 23 inches (see inset of Fig. 5) yields wide-beam patterns as shown in Fig. 5 and provides multipath rejections of only 6 to 14 dB over the frequency band. Thus, with the Nurad horn as a source antenna, the system is much more susceptible to multipath errors. The cross-polarized components are not shown in the

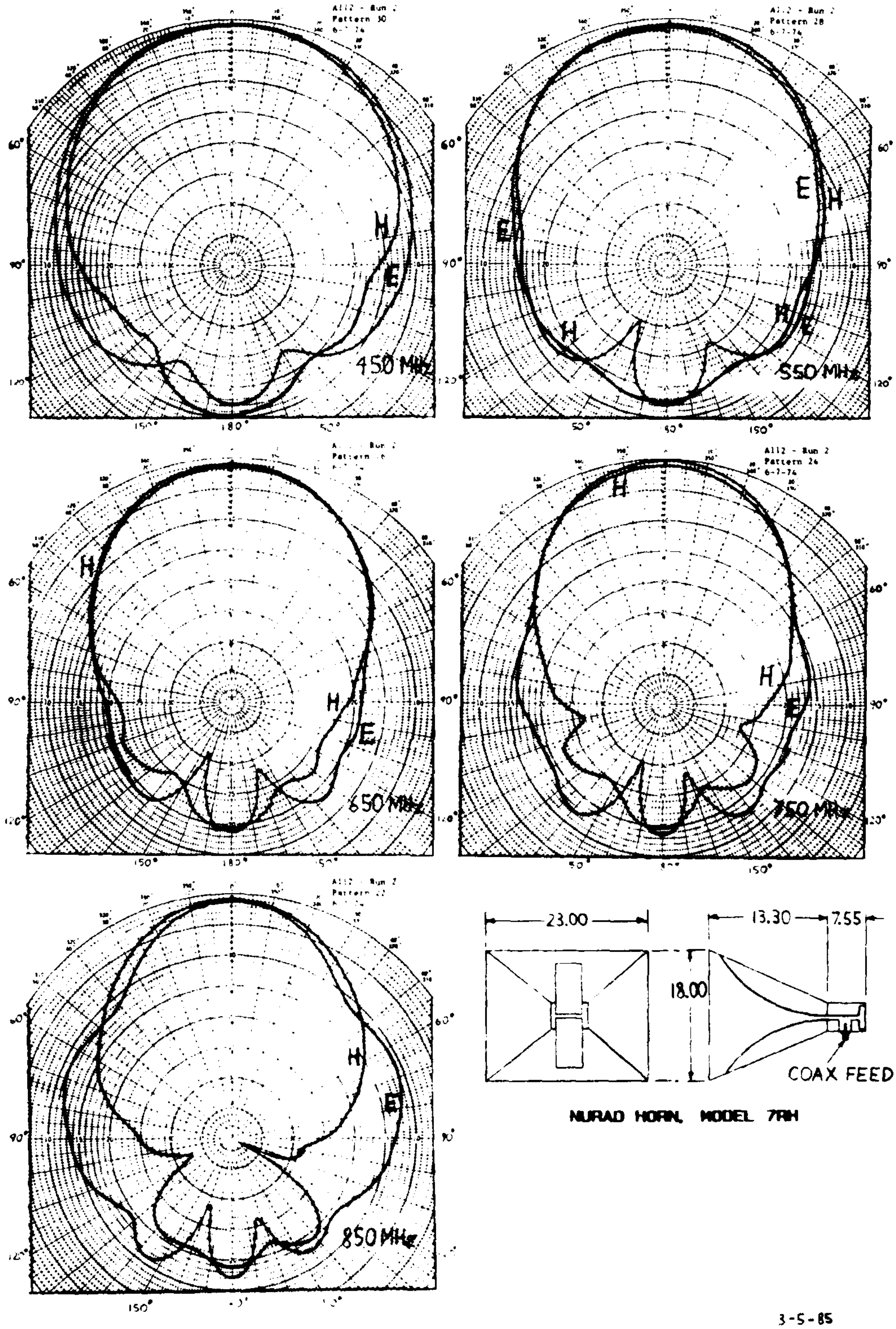


Fig. 5 - Radiation patterns of ridged horn used as source antenna and reference antenna.

patterns of Fig. 5, but they are expected to be ≤ -25 dB. The Nurad horn VSWR response as a function of frequency is shown in Fig. 6. The response is relatively smooth and is ≤ 2:1 over the frequency band.

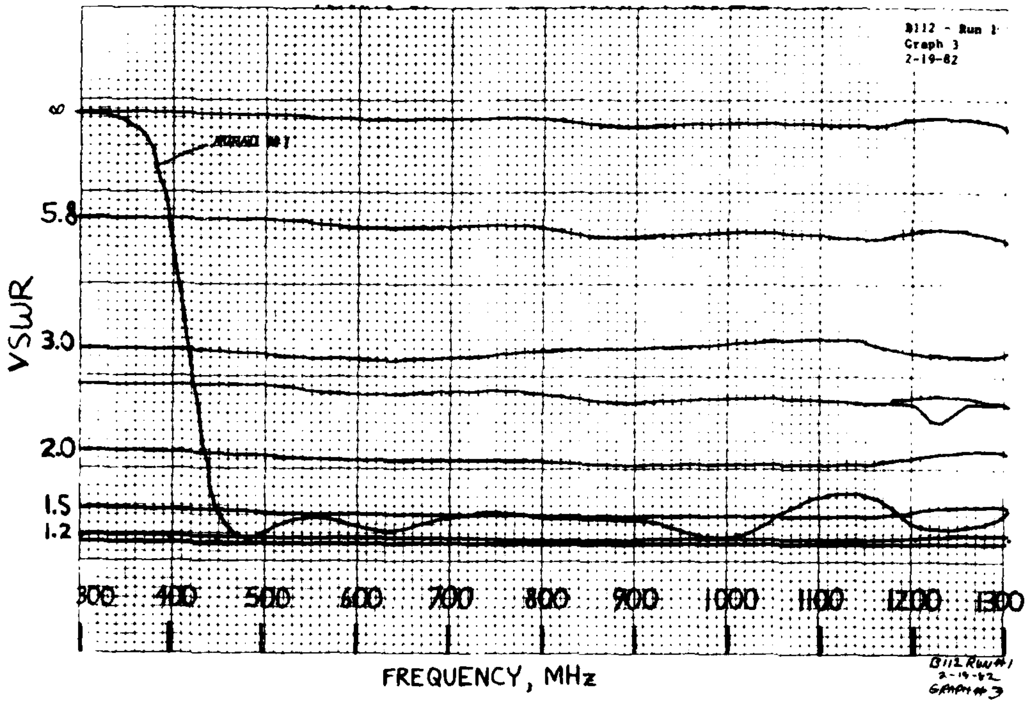


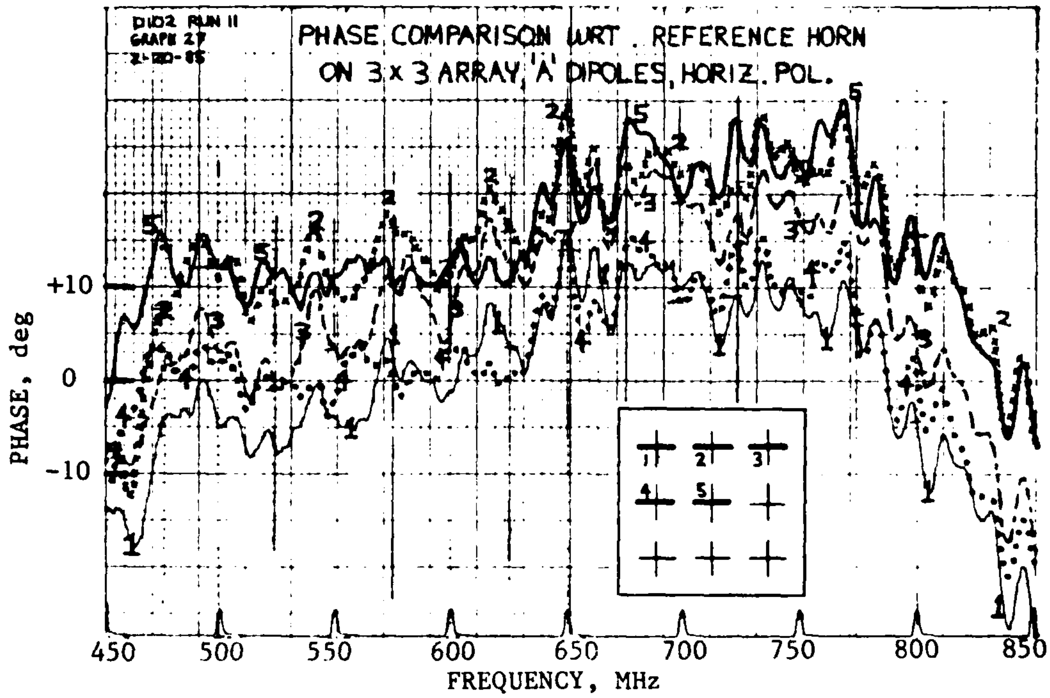
Fig. 6 - VSWR response of ridged Nurad horn.

III. MEASURED RESULTS

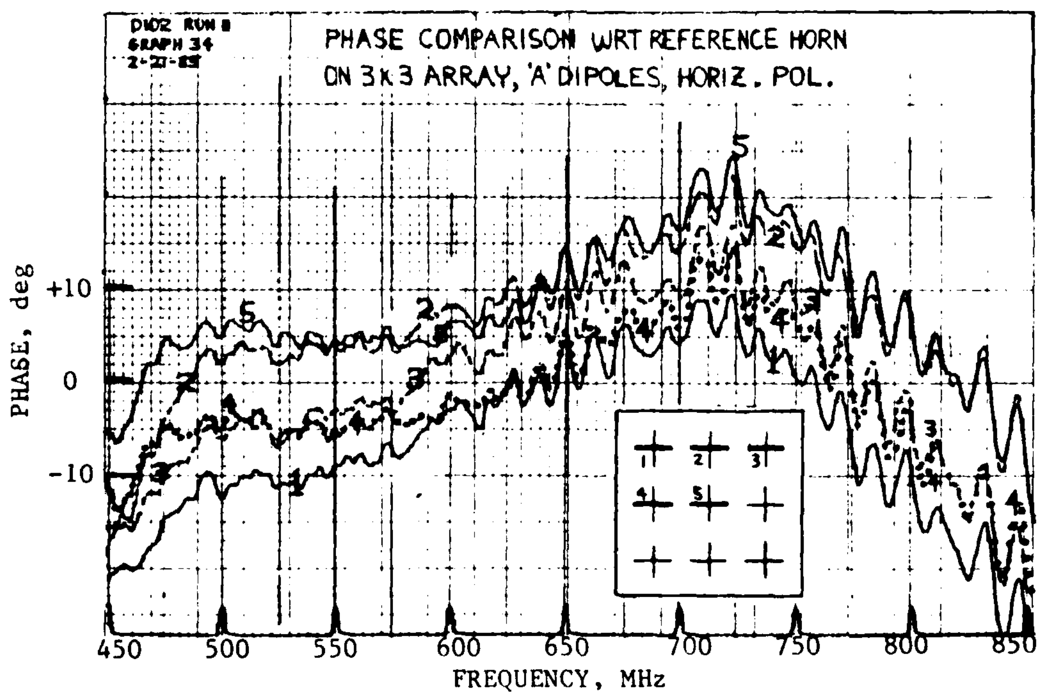
Phase and amplitude measurements, for both horizontal and vertical polarizations, swept over the 450 to 800 MHz frequency spectrum were made with the Nurad horn and also with the 2 × 2 array as source antennas. Although the 9-element array consists of crossed dipoles, only one set of dipoles (A set) were measured. The orthogonal B dipoles were terminated with 50Ω, as well as the unused eight A dipoles during the measurements.

The X-Y recordings show many cyclic variations, and typical graphs are shown in Fig. 7, which illustrate the phase characteristics of dipoles 1 through 5 for the two different source antennas. For all the measurements, the X-Y recordings included the responses of dipoles 1 through 5 and 5 through 9. To assure repeatability, the center dipole response was compared for similarity on each graph. The center dipole is used as the reference antenna for subsequent data processing.

In the initial tests, a Nurad horn was the only source antenna available. In the meantime, the 2 × 2 array was being constructed and tested. The results of dipole set A phase and amplitude measurements with the Nurad horn as a source, are shown in Figs. 8 to 11. The curves were derived from the X-Y recordings (similar to those of Fig. 7a) of phase or amplitude swept over the frequency band. The data points represent the values with respect to the center dipole. The phase data are shown for horizontal and vertical polarization in Figs. 8 and 9, respectively, while the amplitude data are shown in Figs. 10 and 11 for the two polarizations. The curves show little similarity between the vertical and horizontal polarized data. For example, dipole 1 should have identical phase or amplitude responses for either polarization. As an average over the frequency band, the phase and amplitude differences between the horizontal and vertical polarization curves are 4.0° and 0.51 dB,



a) With Nurad Horn (No. 7RH)



b) With 2 x 2 Array

Fig. 7 - Typical X-Y recordings of 3 × 3 array individual dipoles wrt Nurad horn using the Nurad horn and 2 × 2 array as source antennas.

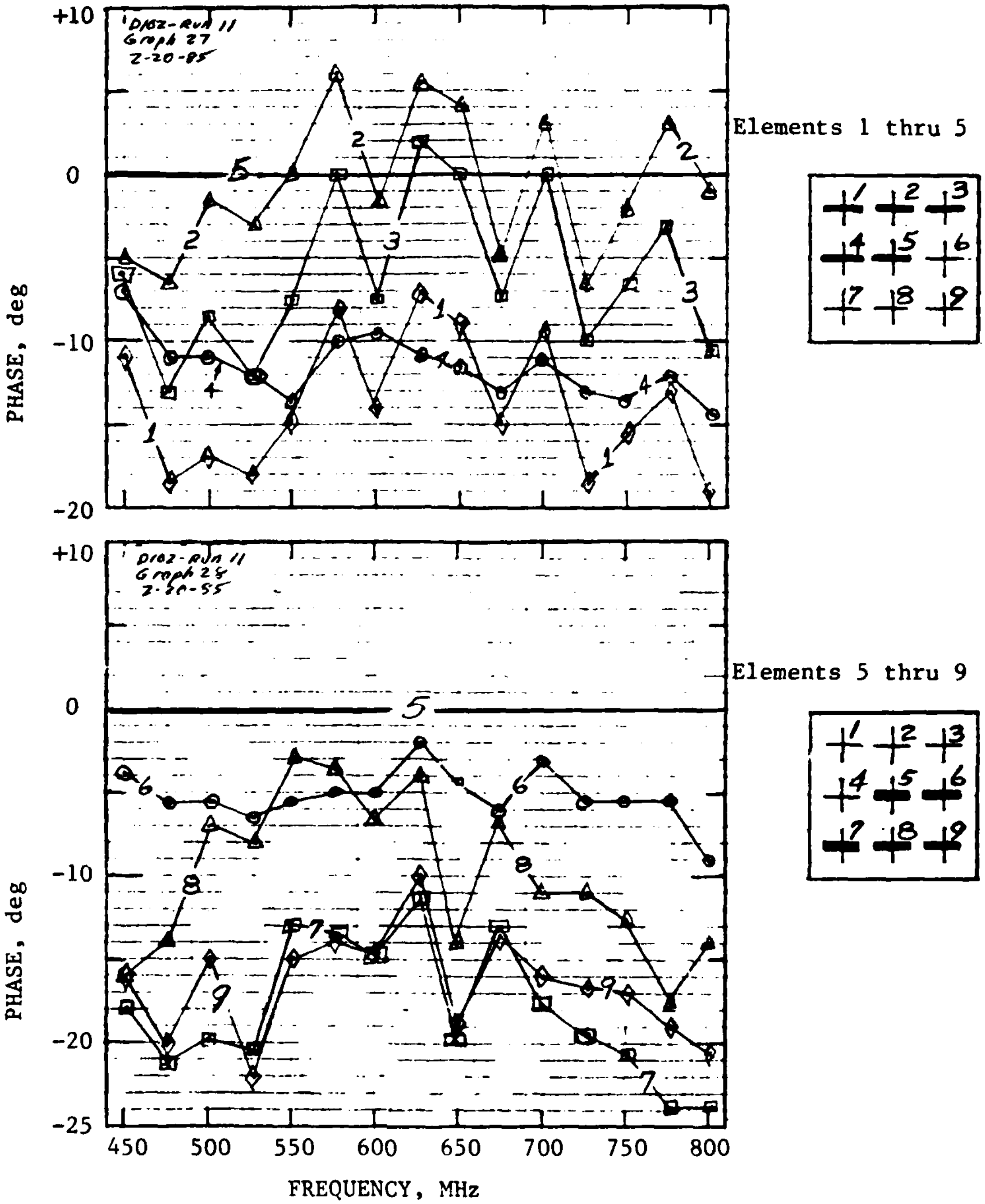


Fig. 8 – 3 × 3 array individual dipole phase response wrt center element using Nurad horn source, horizontal polarization.

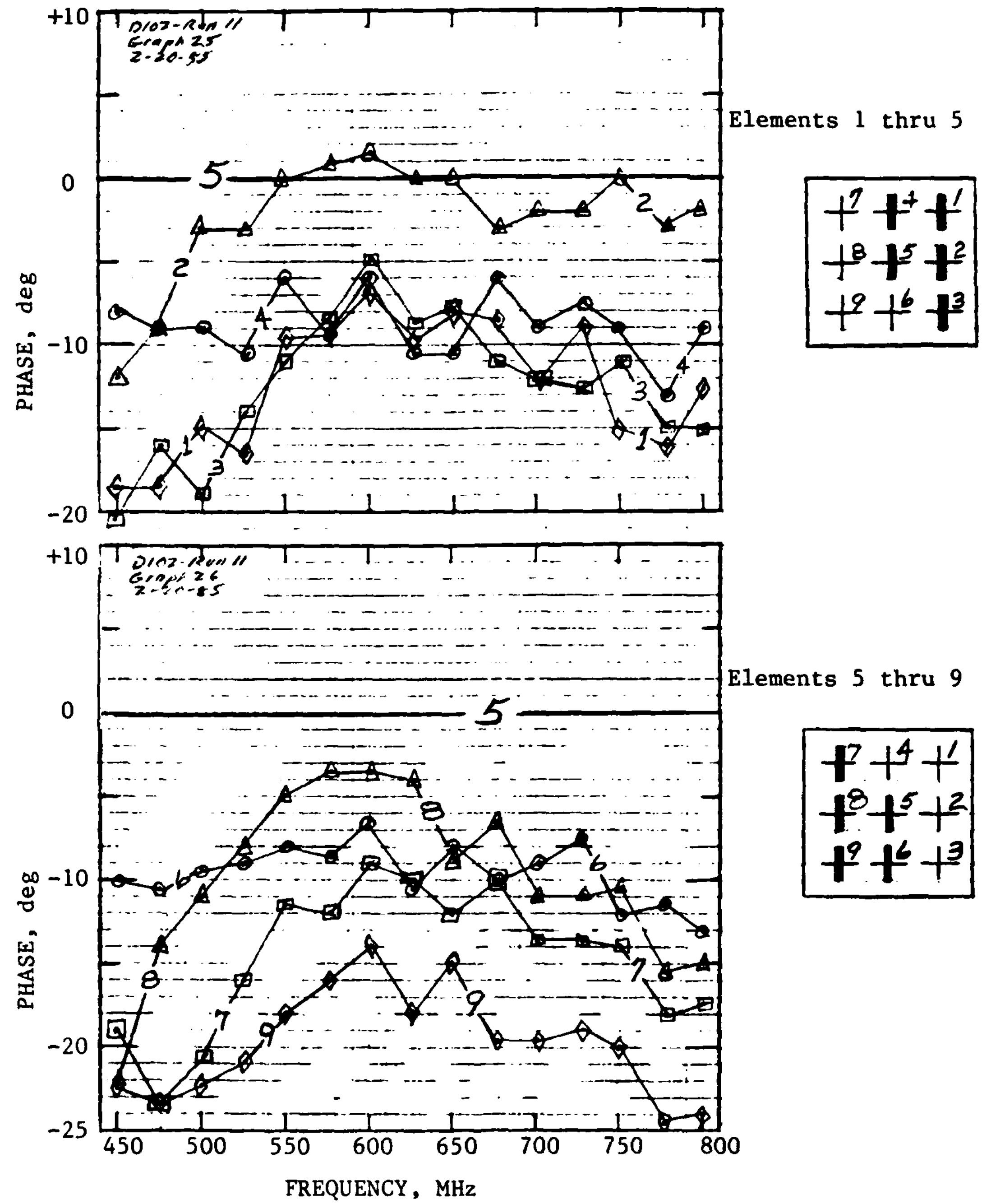


Fig. 9 - 3 × 3 array individual dipole phase response wrt center element using Nurad horn source, vertical polarization.

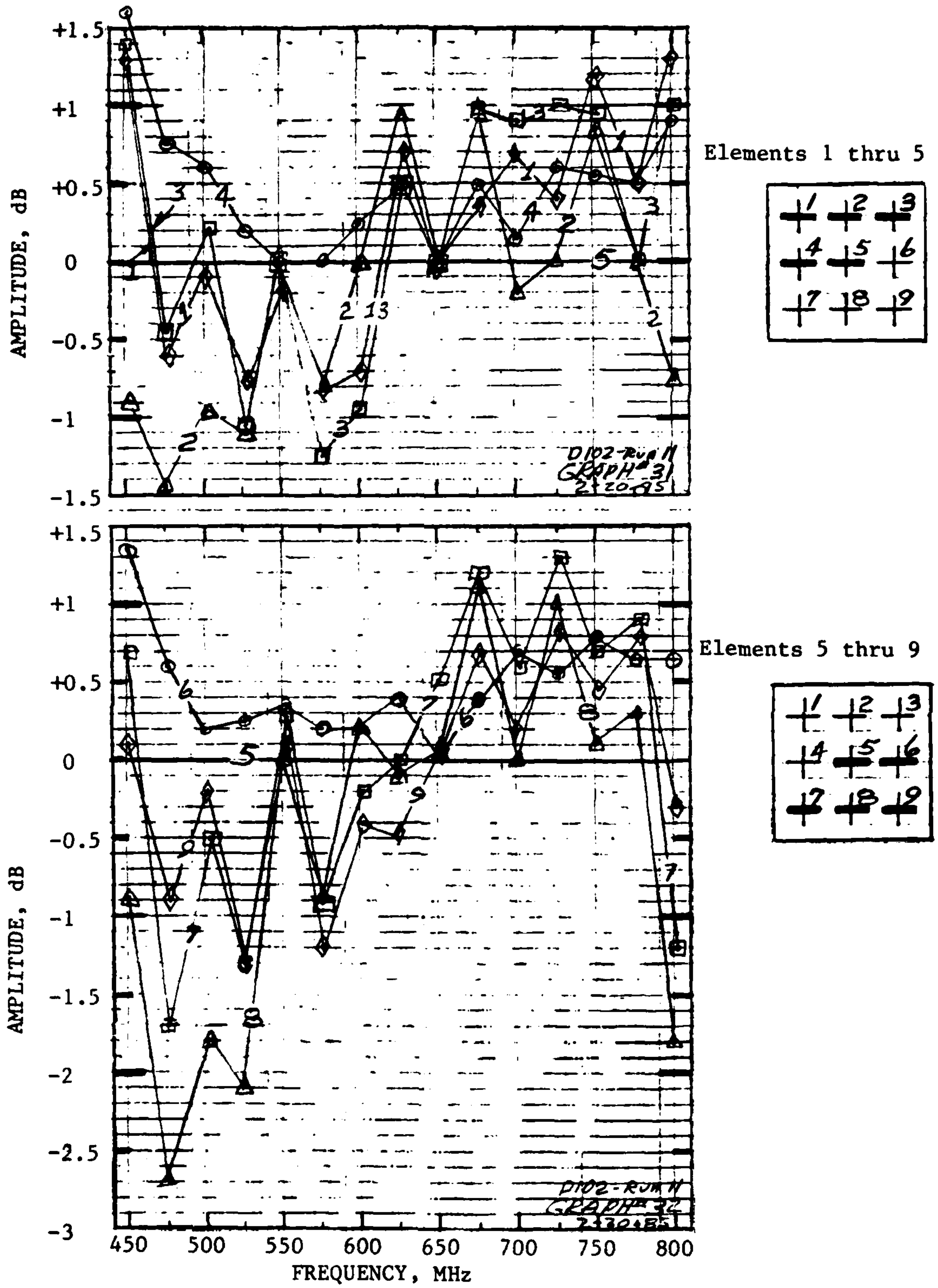


Fig. 10 - 3 × 3 array individual dipole amplitude response wrt center element using Nurad horn source, horizontal polarization.

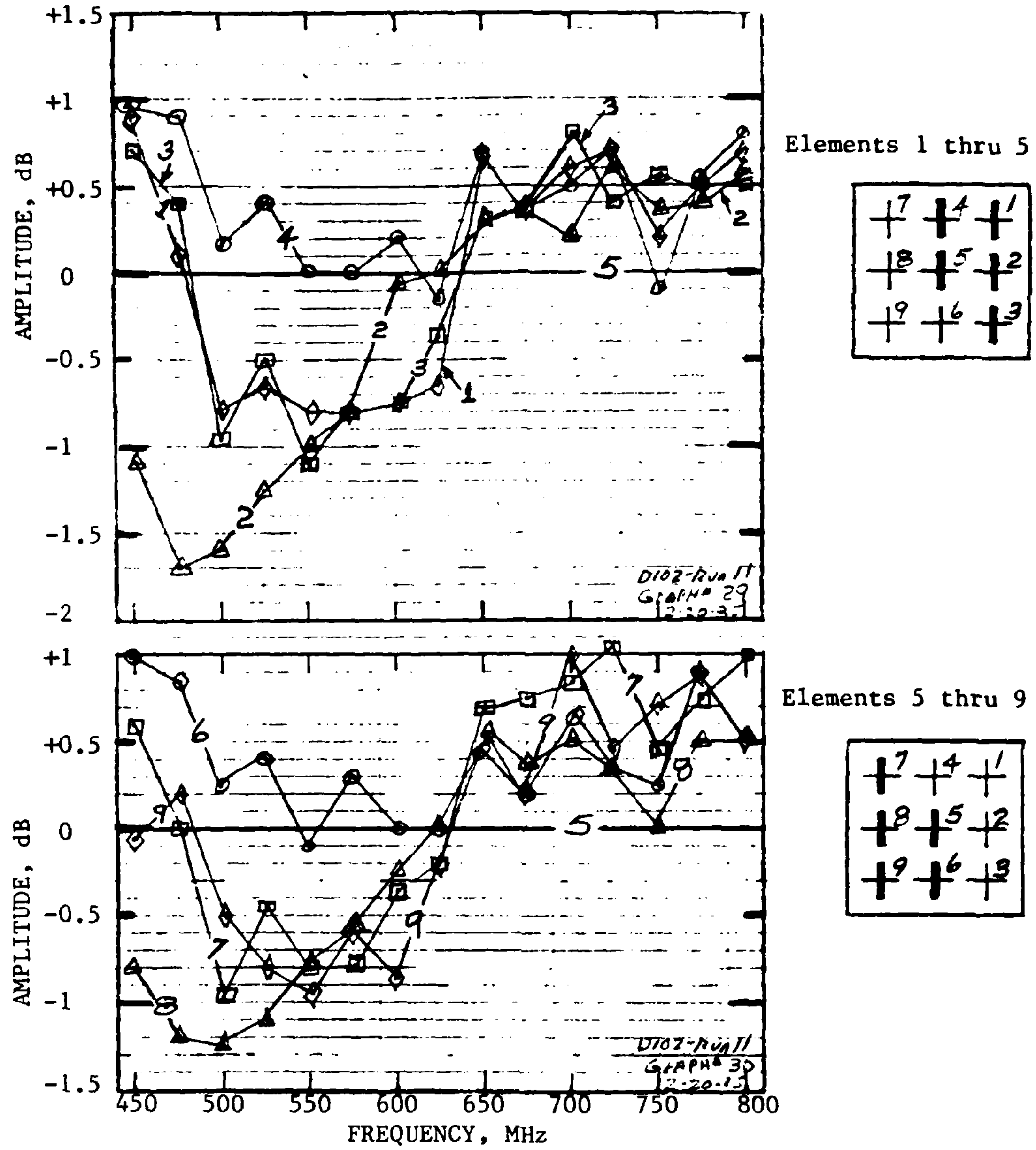


Fig. 11 - 3 × 3 array individual dipole amplitude response wrt center element using Nurad horn source, vertical polarization.

respectively. The average differences between the vertical and horizontal polarization data over the frequency band for the various dipoles are as follows:

Differences Between Vertical and Horizontal Polarization
Nurad Horn Source

Element	Phase, deg Avg	Phase, deg 1σ	Amplitude, dB Avg	Amplitude, dB 1σ
1	4.20	3.30	0.62	0.39
2	3.23	2.21	0.55	0.32
3	6.53	3.99	0.66	0.40
4	3.00	2.44	0.27	0.27
6	4.43	2.10	0.27	0.15
7	4.03	2.47	0.55	0.64
8	2.61	2.04	0.62	0.40
9	3.93	2.27	0.54	0.28
Overall Average	4.00		0.51	

The 3 × 3 array phase and amplitude data for both vertical and horizontal polarization, using the 2 × 2 array as a source are shown in Figs. 12 to 15. The data points represent the values with respect to the center dipole, No. 5. These curves were derivea from the X-Y recordings similar to Fig. 7b.

Similarities of the phase and amplitude curves for the individual dipoles for vertical and horizontal polarization are better with the 2 × 2 array source as compared to the curves with the Nurad horn. Over the frequency band the average phase and amplitude differences for all the dipoles between vertical and horizontal polarizations are 2.01° and 0.22 dB, respectively. Since the Nurad horn has only ~ 17 dB multipath rejection as compared to the >2ɔ dB for the 2 × 2 array, the data with the 2 × 2 array is considered more reliable and should be used for characterizing the relative transfer functions. The following table summarizes the average differences over the frequency band fo

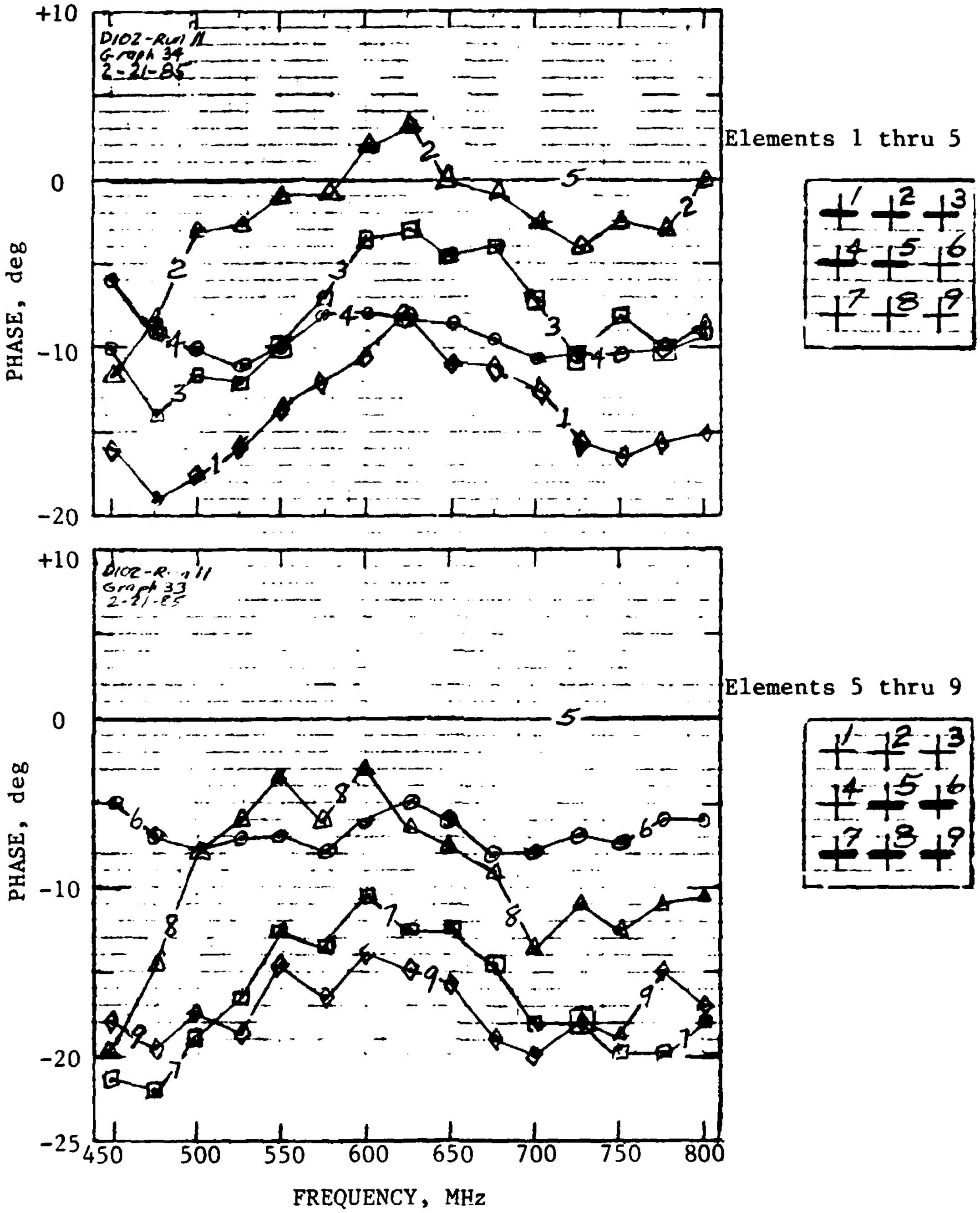


Fig. 12 - 3 × 3 array individual dipole phase response wrt center element using 2 × 2 array source, horizontal polarization.

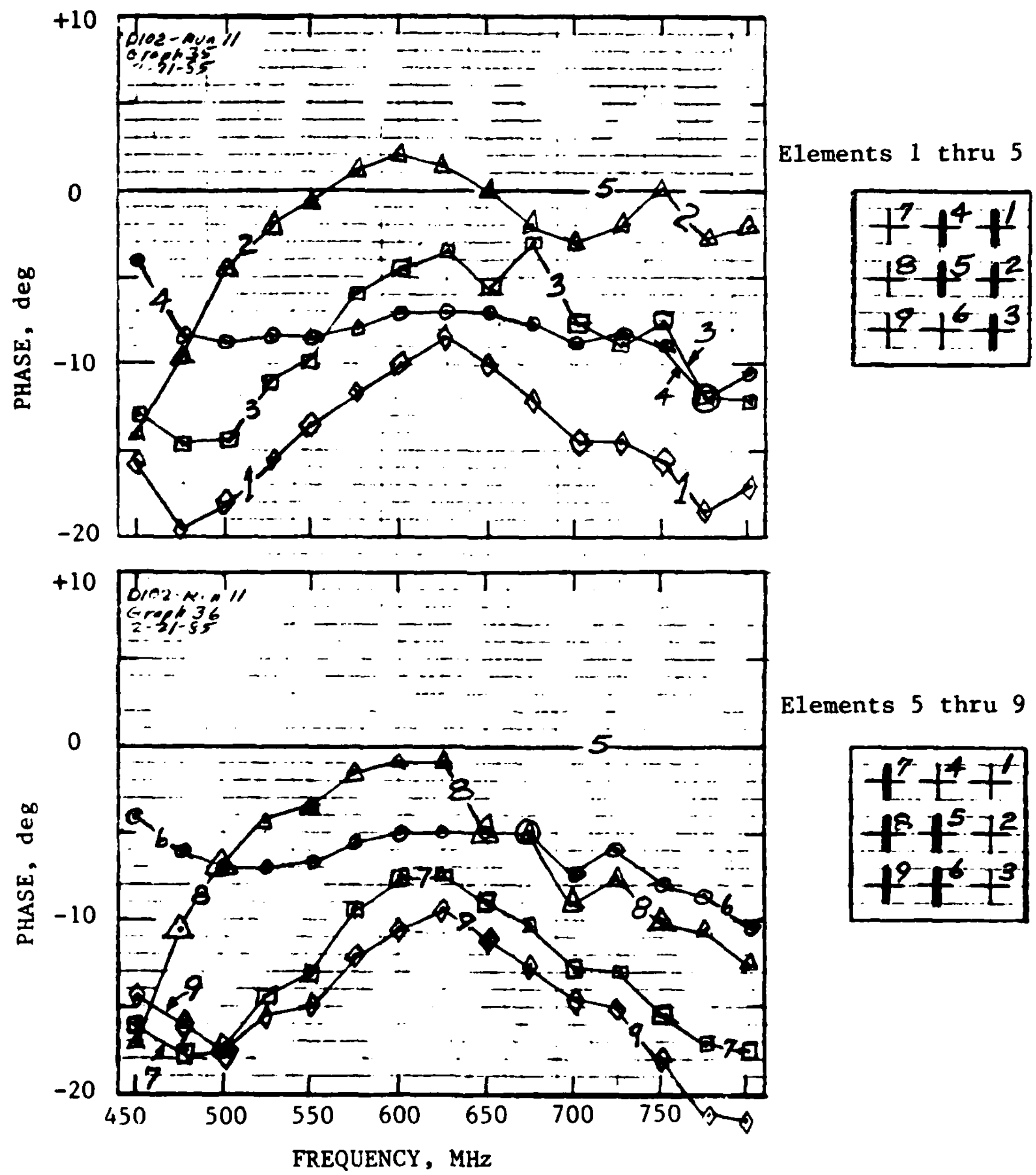


Fig. 13 - 3 × 3 array individual dipole phase response wrt center element using 2 × 2 array source, vertical polarization.

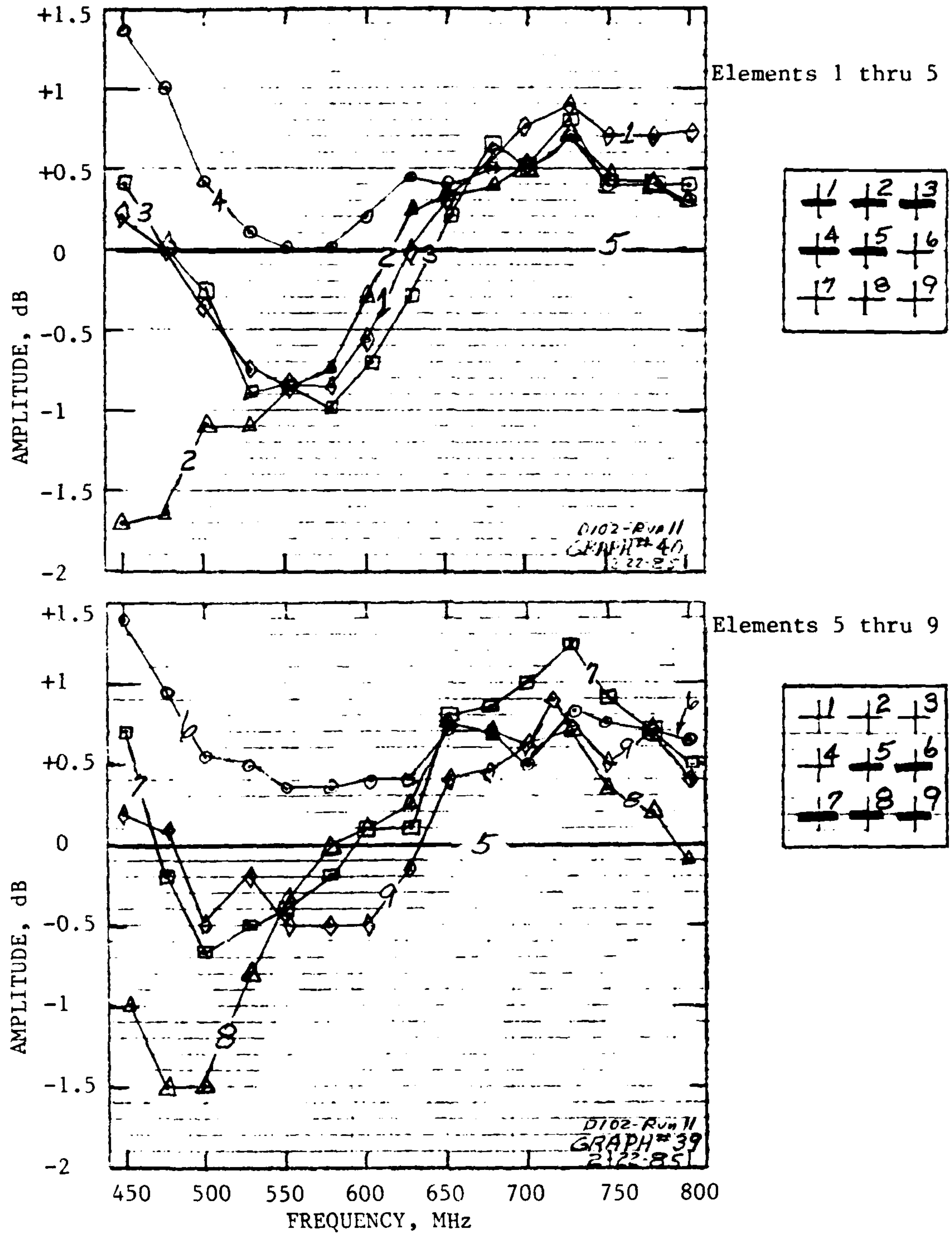


Fig. 14 - 3 × 3 array individual dipole amplitude response wrt center element using 2 × 2 array source, horizontal polarization.

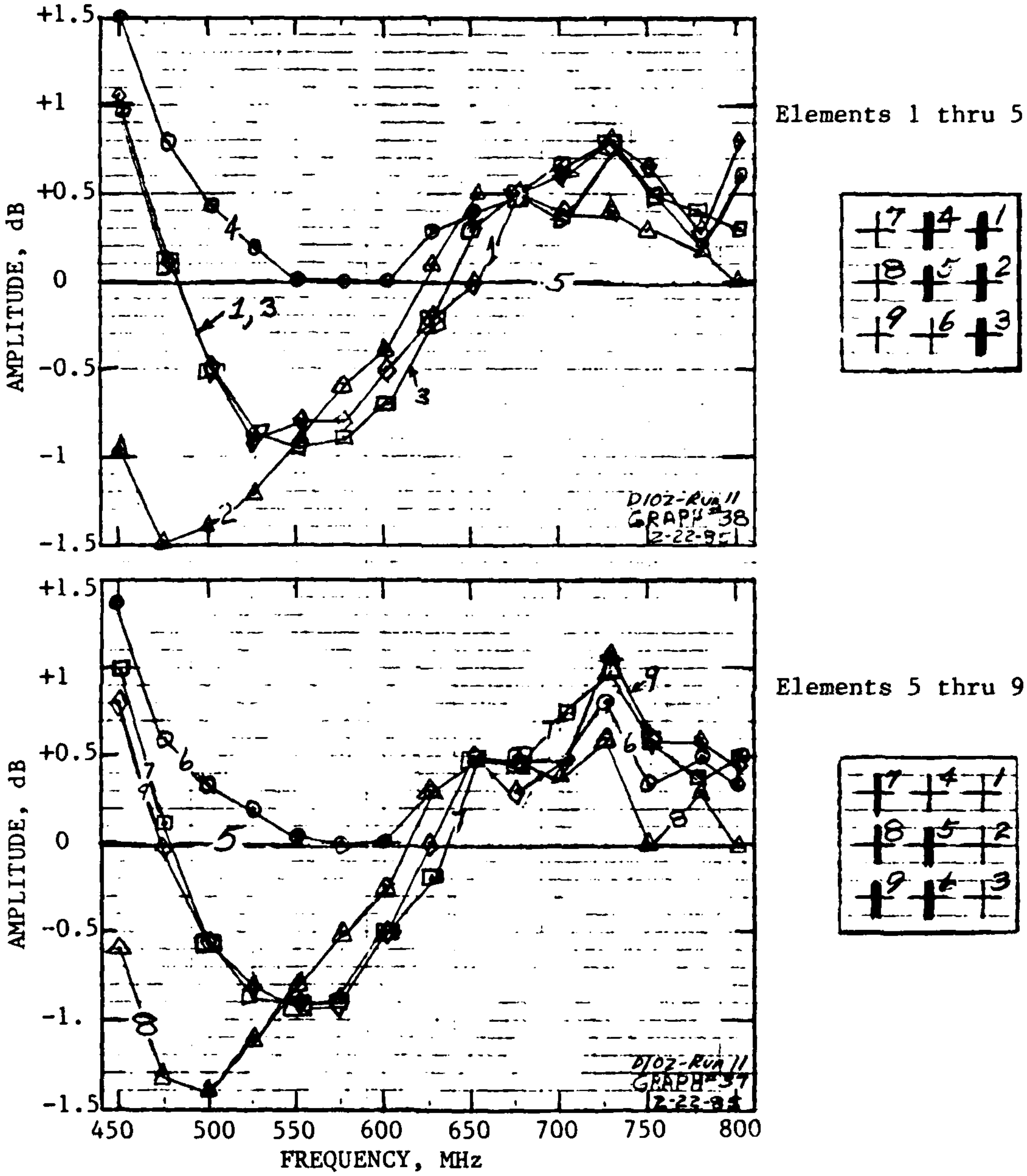


Fig. 15 - 3 × 3 array individual dipole amplitude response wrt center element, using 2 × 2 array source, vertical polarization.

the phase and amplitude from the vertical and horizontal polarization data obtained by using the 2 × 2 array as a source antenna:

Differences Between Horizontal and Vertical Polarization
2 × 2 Array Source

Element	Phase, deg Avg	Phase, deg 1σ	Amplitude, dB Avg	Amplitude, dB 1σ
1	0.95	0.81	0.17	0.22
2	0.87	0.96	0.22	0.19
3	1.31	1.02	0.21	0.37
4	1.46	0.68	0.17	0.17
6	1.42	1.25	0.26	0.18
7	3.51	1.66	0.25	0.15
8	2.86	1.43	0.26	0.15
9	3.69	1.98	0.21	0.20
Overall Average	2.01		0.22	

This table illustrates that the differences between the transfer function for vertical and horizontal polarizations are relatively small (~ half those obtained with the Nurad horn source). Figures 16 to 21 show the individual phase and amplitude responses of each dipole for both vertical and horizontal polarizations. Ideally, the horizontal and vertical polarization curves should be identical; nevertheless, the similarities are reasonably good. The differences probably represent the measurement errors. The average values would provide a good representation of the transfer functions.

From physical symmetry of the array, the four, corner elements (1, 3, 7 and 9) should have the same transfer function. Similarly, the collinear elements (4 and 6) and the parallel elements (2 and 8) should be identical. To provide a qualitative comparison, the phase and amplitude curves of ele-

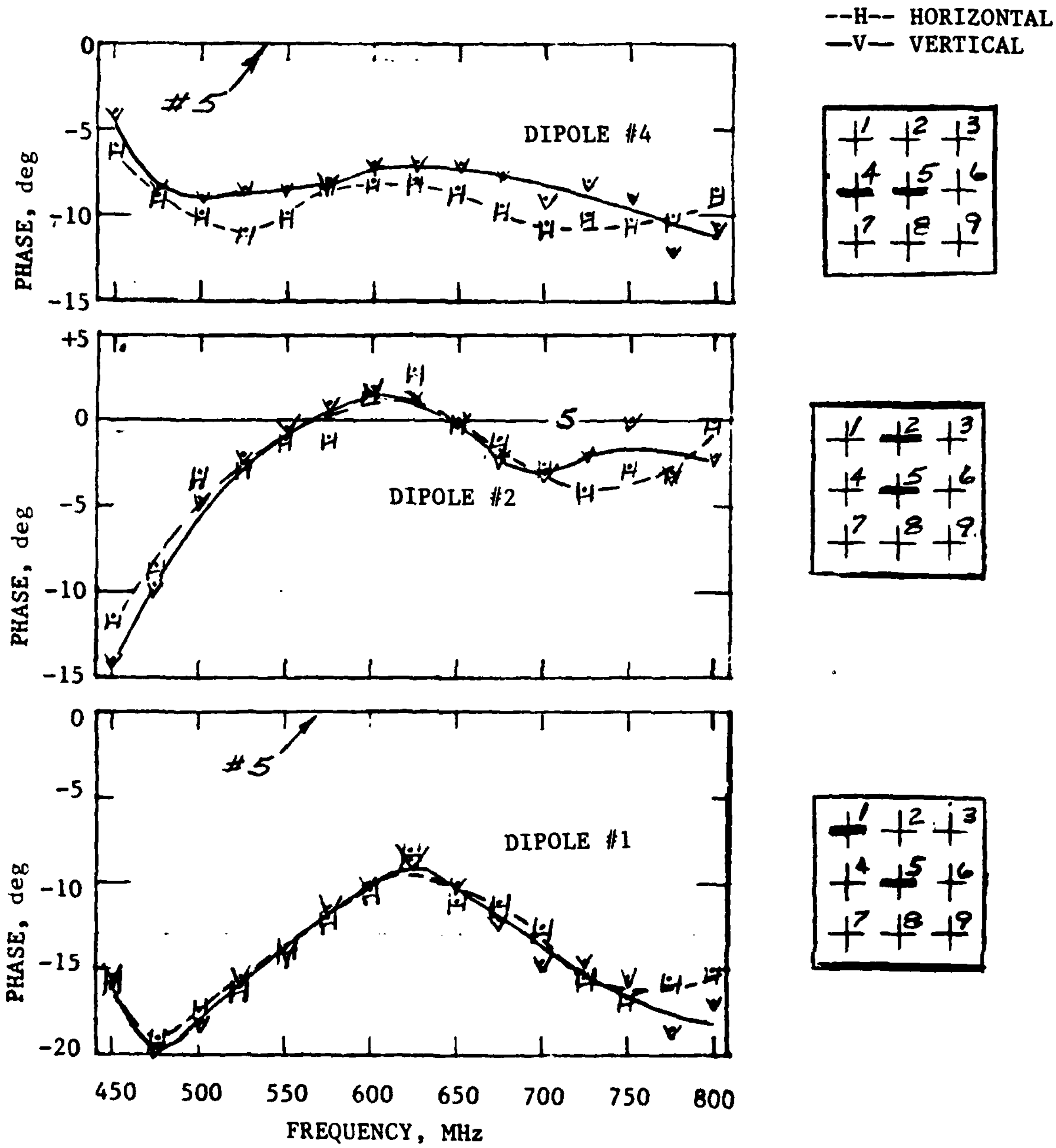


Fig. 16 - Comparison of horizontal and vertical polarization responses of individual dipoles, Nos. 4, 2 and 1 (2 × 2 array source), wrt center element.

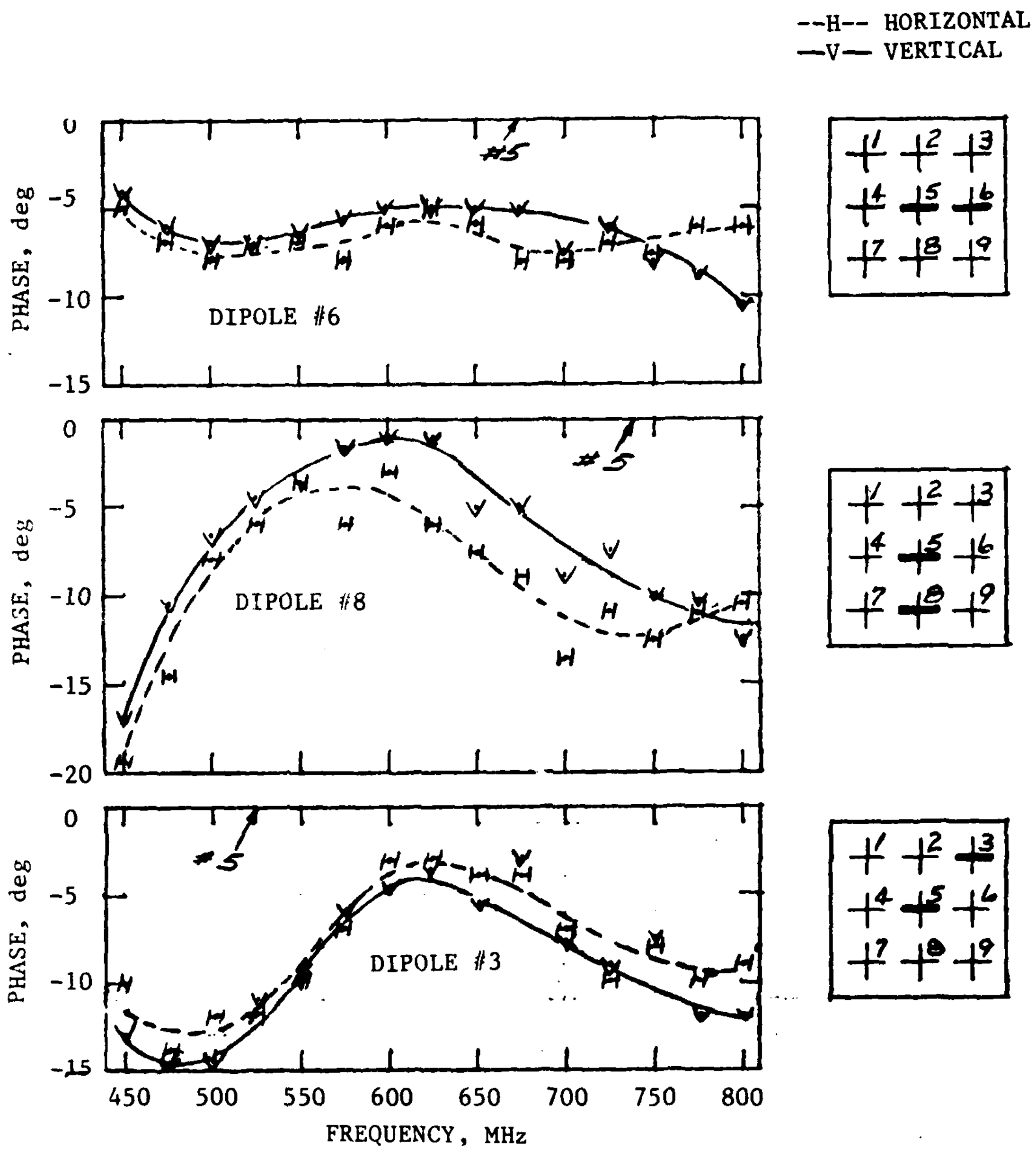


Fig. 17 - Comparison of horizontal and vertical polarization phase responses of individual dipole, Nos. 6, 8 and 3 (2 × 2 array source), wrt center element.

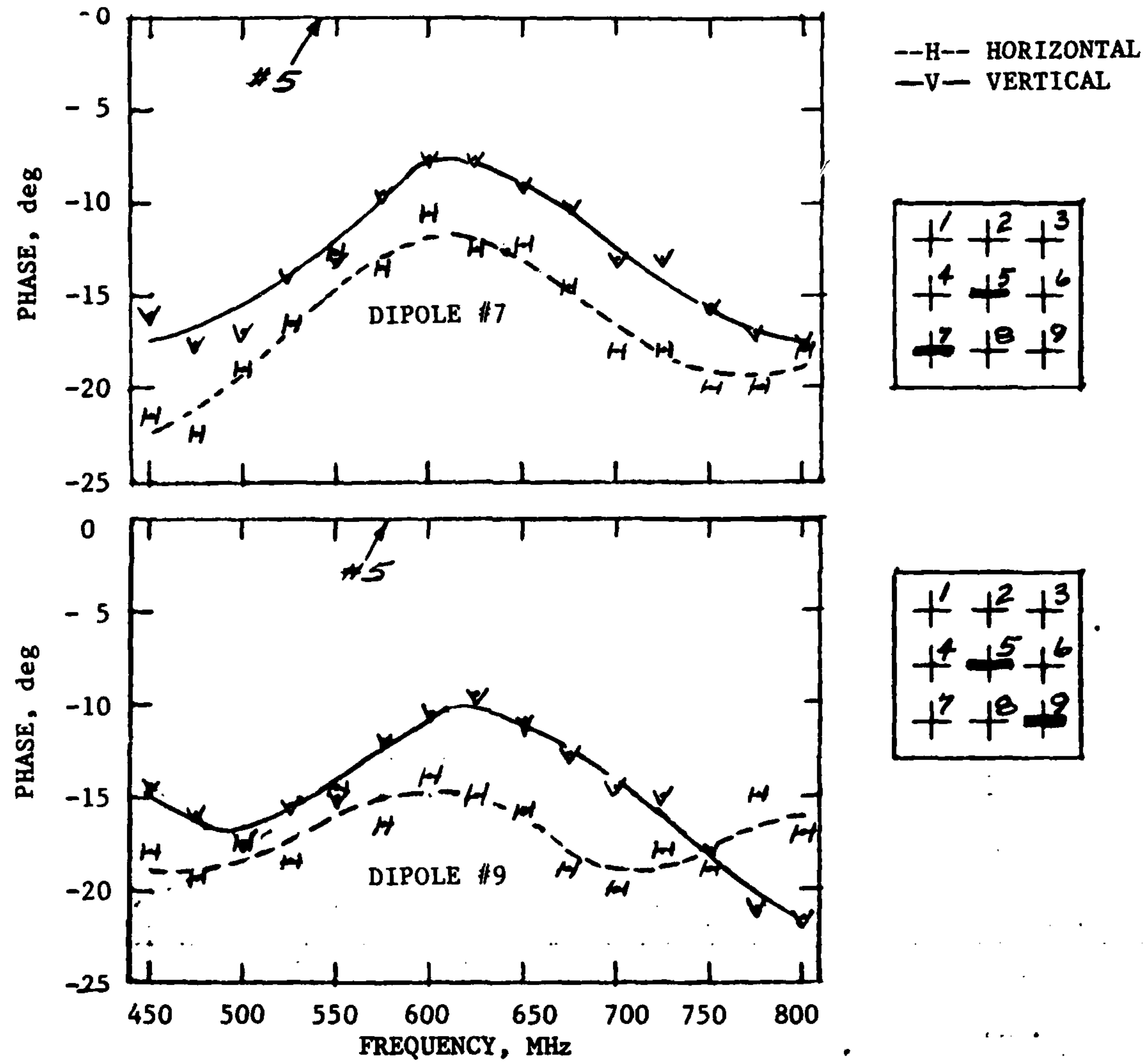


Fig. 18 - Comparison of horizontal and vertical polarization phase responses of individual dipole, Nos. 7 and 9 (2 × 2 array source), wrt center element.

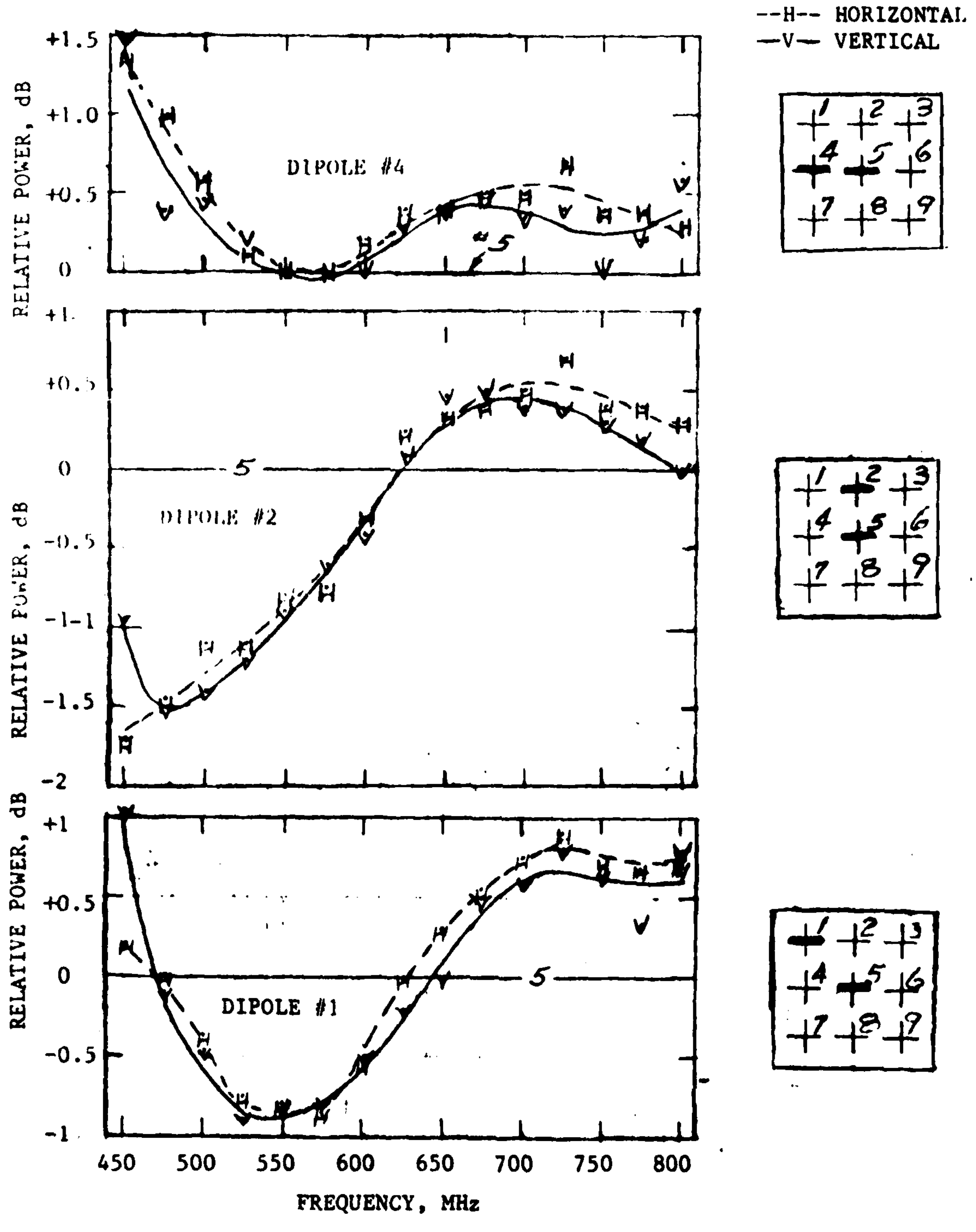


Fig. 19 - Comparison of horizontal and vertical polarization amplitude responses of individual dipole, Nos. 4, 2 and 1 (2 × 2 array source), wrt center element.

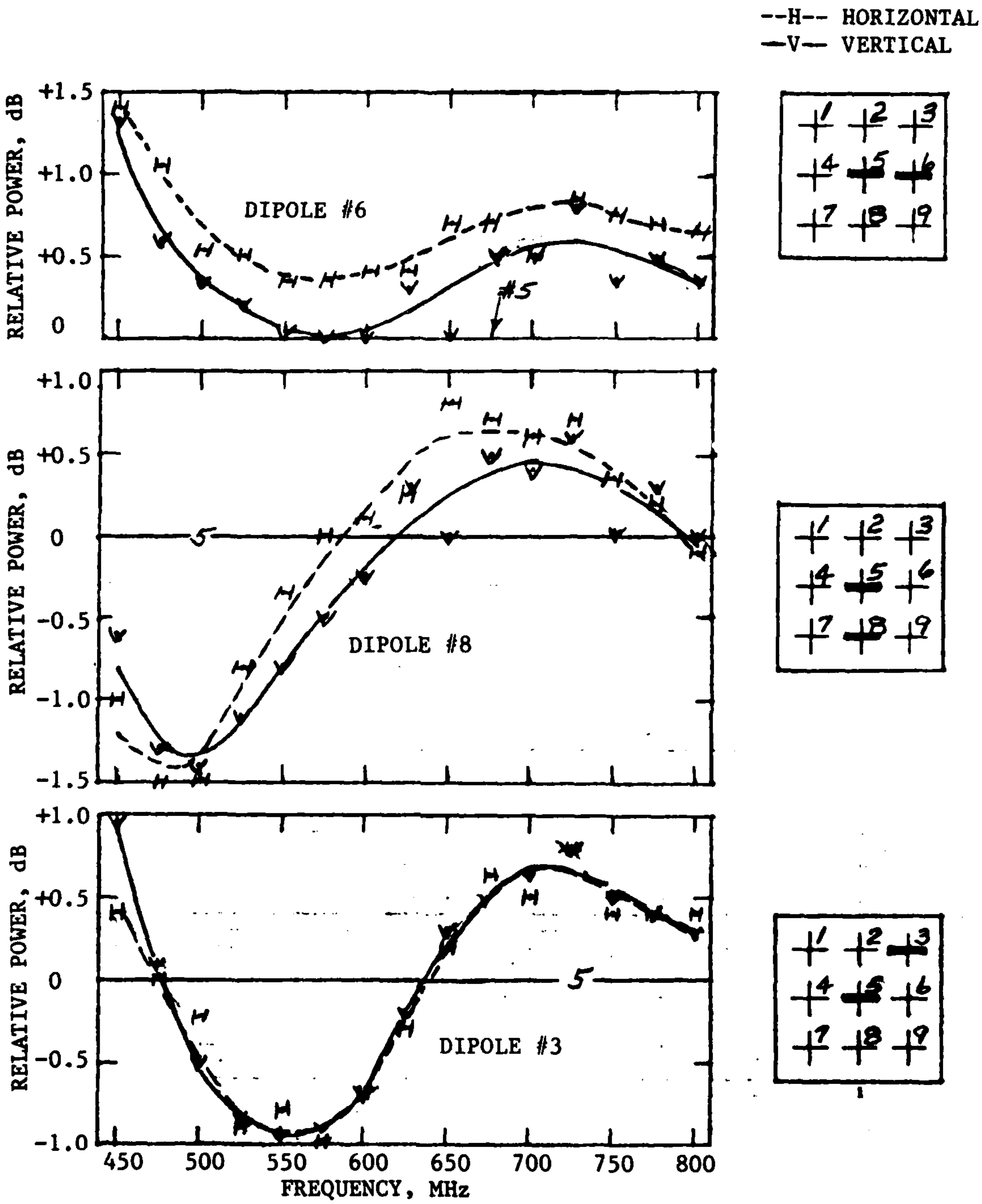


Fig. 20 - Comparison of horizontal and vertical polarization amplitude responses of individual dipole, Nos. 6, 8 and 3 (2 × 2 array source), wrt center element.

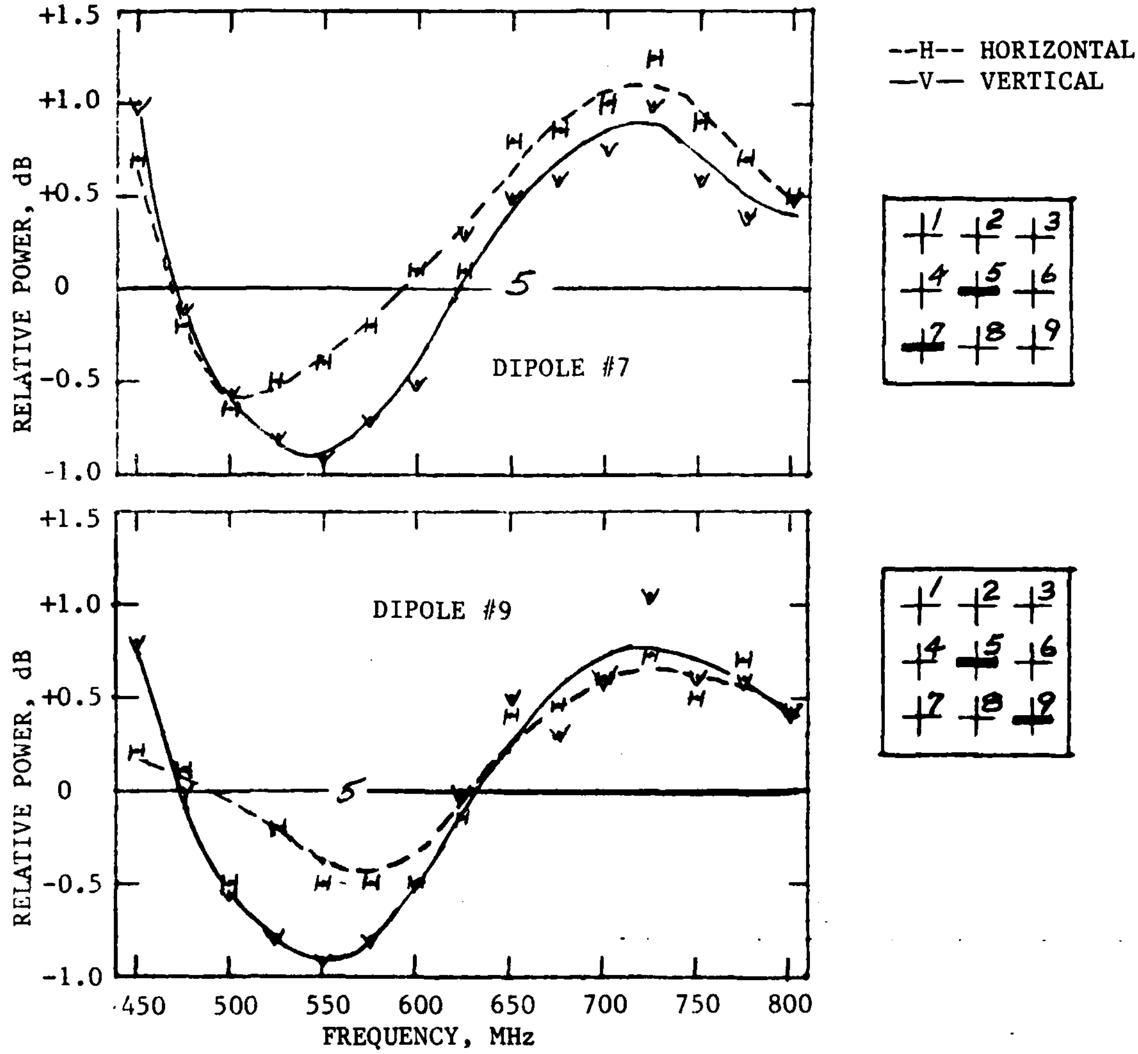


Fig. 21 - Comparison of horizontal and vertical polarization amplitude responses of individual dipole, Nos. 7 and 9 (2 × 2 array source), wrt center element.

ments 2 and 8, 4 and 6 and 1, 3, 7, and 9 (both polarizations) were averaged and plotted in Figs. 22 and 23. The data point represents the average and the vertical bar is the standard deviation. The dots represent the maximum and minimum measured values.

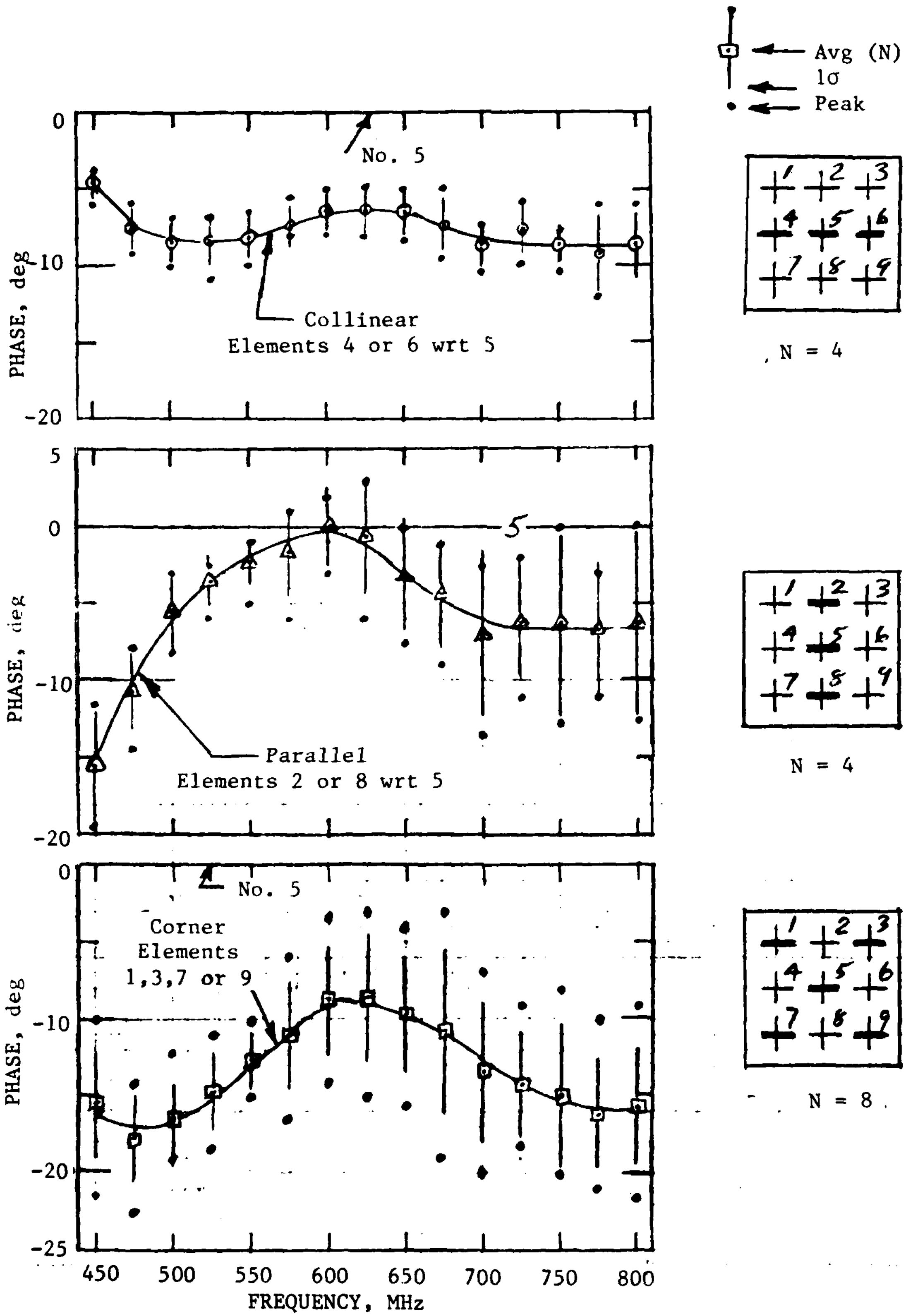


Fig. 22 – Averaged phase response of symmetrical dipole wrt center element in 3 × 3 array.

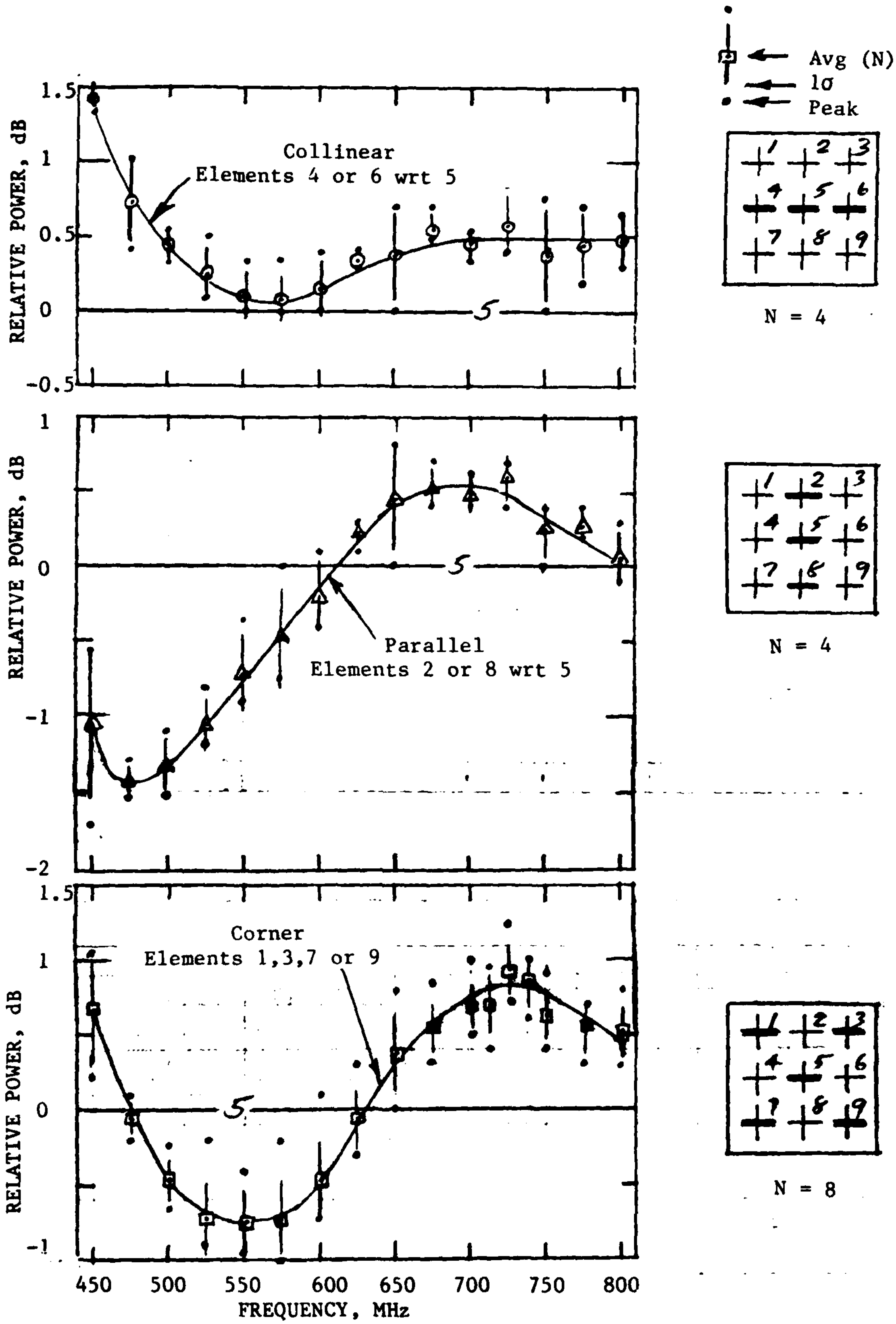


Fig. 23 - Averaged amplitude response of symmetrical dipoles wrt center element in 3 × 3 array.

IV. CONCLUSIONS

Referenced to the center dipole, the phase and amplitude characteristics for the individual dipoles of a 9-element array (3 × 3 configuration) for both vertical and horizontal polarizations are presented. Comparison between the results obtained with a wide-beam horn illuminating source and a narrow-beam, 4-element diagonal array source show that multipath rejection is an important factor in these measurements, and therefore the data with the array source should be used.

The individual dipole responses for vertical and horizontal polarization are very close with an overall average phase and amplitude deviation of 2.01° and 0.22 dB, respectively. From physical symmetry, the four corner elements should yield identical results, and likewise, the parallel elements 2, 8 and the collinear elements 4, 6.

V. REFERENCES

1. H. E. King and J. L. Wong, "1.8:1 Bandwidth UHF 3 × 3 Array of Crossed Open-Sleeve Dipoles," Aerospace Technical Report TR-0073 (3404)-1, SAMSO TR-72-178, 30 June 1982.

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, environmental hazards, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence and microelectronics applications.

Electronics Research Laboratory: Microelectronics, GaAs low noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter wave, microwave technology, and RF systems research.

Materials Sciences Laboratory: Development of new materials: metal matrix composites, polymers, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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